EVALUATION OF INCREASED VENTILATION RATES AND ENERGY CONSERVATION MEASURES

AT

Four New York State Schools

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INTRODUCTION AND GENERAL BACKGROUND

The Energy Solutions Division of Science Applications International Corporation (SAIC) prepared this report as a continuation of the New York State Energy Research and Development Authority's (NYSERDA's) efforts to help schools both mitigate high radon levels and improve overall indoor air quality in a cost-effective, energy-efficient manner.

General Background

Adequate ventilation is one of the most important ways to maintain the health and well-being of students and staff in a school building. Properly supplying outdoor air when people are in the building is essential to good indoor air quality. Lack of sufficient outdoor air may create "stuffiness" due to increased carbon dioxide, odors, and moisture build-up. In turn, these factors may increase drowsiness and inattentiveness, interfering with the school's primary mission of educating students. Other, less noticeable effects may also occur, such as higher radon concentrations, reduced oxygen levels, and increased airborne bacteria levels.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 62-1989, Ventilation for Acceptable Indoor Air Quality, requires that outdoor air be provided to classroom spaces at a rate of 15 cubic feet per minute (cfm) per person during occupied periods. However, energy conservation and cost-saving goals can work against meeting these ventilation standards. In fact, energy cost-reduction measures are sometimes implemented with little regard for their impact on ventilation and indoor air quality. However, proper ventilation levels can be achieved with minimal negative effects on energy use and cost, as the case studies discussed in this report illustrate.

The first objective of these projects was to evaluate the energy impacts of ventilation-related radon-mitigation measures. Increasing outdoor air ventilation can reduce radon levels by diluting concentrations in the school and positively pressurizing the occupied space to limit the intake of radon from the soil. The evaluations identified the baseline (or pre-mitigation) energy consumption and then predicted the increase in annual energy costs (post-mitigation) from the proposed measures. In addition, SAIC assessed the potential for improving the school's energy efficiency through energy conservation measures (ECMs) and operation and maintenance (O&M) improvements identified by SAIC or planned by the school.

The energy impacts were analyzed using a building simulation. The school's pre- and post-mitigation conditions were modeled using the computer simulation program ASEAM3. ASEAM3 was developed by the U.S. Department of Energy as a tool to quantify the energy consumption of building energy systems. For each of the schools, a base-case model for the existing school building was developed and calibrated to historical energy bills. The energy consumption predicted by the base-case model was very close to actual energy bills. The modeling-based results predicted that implementing efficiency improvements would offset potential energy consumption increases resulting from increased ventilation rates.

The database summarizes the results of the study, including base-case energy consumption, and the change in oil and electricity consumption resulting from the ventilation measure and the ECMs. The database also presents the installed costs for the ECMs and their payback periods. The values in this database came from the results of the ASEAM3 computer simulations and a utility bill analysis that was the basis for calibrating the base-case computer simulation model.

Finally, because the third and fourth schools were undergoing significant capital improvements, the studies also developed future-year energy budgets for those schools. The energy budgets were developed by simulating the planned additions, as well as the existing sections (after including all the measures).

Summary of Findings

SAIC completed the four evaluations from July 1995 to November 1996. This summary consolidates the results of the four studies and includes computations performed on a large number of building parameters to arrive at useful results that can be used by school facility managers throughout New York State. Many results are presented on a per-occupant and per-square-foot basis.

In the four schools studied, the energy penalty did not preclude increasing outdoor air ventilation rates to meet ASHRAE Standard 62-1989 of 15 cfm per occupant in classrooms. The summary also illustrates that implementing ECMs could offset any increase in energy consumption resulting from higher ventilation rates. In fact, energy cost *savings* are possible through implementing ECMs and increasing ventilation. Depending on baseline ventilation rates and the type of ventilation measures, the studies illustrate the following:

- Increasing outdoor air ventilation rates can increase the total annual energy costs (heating fuel and electricity) 2.6-22.5%, depending on specific building and technology parameters.

- Implementing ECMs can reduce total annual energy costs 10-36.8%. However, simple paybacks vary depending on ECM type. Certain measures had paybacks as low as 1.2 years, while other paybacks exceeded 10 years.

- Some measures with long paybacks were not recommended by SAIC/NYSERDA, but were planned by the schools as part of capital improvement projects and had to be implemented due to need rather than energy economics. Replacing windows and doors, as well as improving the roof's structural integrity while insulating it, fell into the long-paying category.

- On the other hand, measures such as lighting retrofits, controls improvements (nighttime setbacks and reducing overheating), roof insulation, and occupancy sensors with paybacks shorter than 10 years were recommended by SAIC and NYSERDA.

- Overall future energy *savings* of 7.4-14.2% can be achieved by implementing ECMs to offset the penalty caused by increased ventilation rates. In addition to the above, the report includes some general recommendations:

  - To avoid unnecessary ventilation penalties, designers should not specify ventilation rates much higher than the ASHRAE guideline.

  - Properly sizing HVAC equipment such as boilers, pumps, and relief fans is crucial, as oversizing increases installed and annual energy costs and may not comply with radon mitigation/IAQ guidelines. For example, a school may be able to maintain the same level of backup provided by two 100hp sectional boilers with a properly sized 150hp modular boiler consisting of multiple small boilers (e.g., six 25hp modular boilers). Modular boilers have lower standby losses and therefore consume less energy than large sectional boilers, especially during standby and partload conditions. In other words, design engineers should consider energy efficiency in all their designs.

- For schools that were already energy-efficient, a minimal number of ECMs were identified and recommended.

- Inappropriate/excessive exhaust fan operation may not comply with radon-mitigation recommendations and may increase the school's future energy use unnecessarily. Thus, the case study analysis assumed that not all exhaust and relief fans were operated and that the ventilation system kept the building under positive pressure.

Simplified "What-If" Analysis

To help facility managers of electrically heated schools, and because all four schools are heated by fossil fuels, the computations also include a simplified "what if" analysis that presents energy penalties and savings assuming the schools were electrically heated.

In general, if the schools were electrically heated:

- The ventilation penalty would increase.

- ECM energy cost savings would increase, and paybacks would improve.

- Combined savings would increase in most cases.

Follow-Ups

This study also included a follow-up that compared SAIC's modeling-based predictions to recent utility bills for the first two schools. The follow-ups were initiated by utility bill analyses, followed by site visits, weather-adjusted utility bill analyses, and report writing.

SAIC explained the differences between predicted and actual energy consumption observed at the schools by analyzing the energy impacts of:

- "As installed" radon-mitigation measures. The radon measures were not implemented as exactly specified in previous NYSERDA evaluations. The facilities appeared to have brought in outdoor air flows different from those originally recommended by NYSERDA and modeled by SAIC.

- Any ECMs or O&M improvements implemented. Not all of the ECMs and O&Ms identified by SAIC were implemented.

- Any operational changes.

- Different weather patterns.

In spite of the above, model predictions were in reasonable agreement with weather-adjusted utility bill analyses. Weather-adjusted analyses were needed because weather variations were significant and could not be ignored. Additional analyses, using simplified and bin approaches, were used to explain the impacts of the above factors on energy consumption patterns.

Case Study #1

School #1 is a 77,000-square-foot brick building in Tioga County. This middle school was built in three stages, the original structure in 1931, followed by additions in 1954 and 1961. The school has about 600 students and approximately 100 teachers and staff.

A base-case model for the existing school was developed and calibrated to historical energy bills. Annual energy costs determined by the model were $67,821, as follows:

- #2 heating oil consumption - 41,255 gallons per year - annual cost $22,690 ($0.55 per gallon).
- Electric energy use - 376,086 kWh per year - annual cost $45,130 - aggregate electricity cost (including demand) - $0.12 per kWh.
- Cost per occupant - $96.89 per year ($67,821/700).

Insulating the roof would reduce total annual energy consumption (oil and electricity) by 10% ($6,751). The energy cost savings per occupant would be $9.64 per year. The estimated implementation cost of $500,000 would make the simple payback period (SPB) greater than 30 years. Energy economics alone cannot justify this measure.

Increasing the outdoor air ventilation rate would increase the total annual energy cost (#2 oil and electricity) by 2.6% ($1,743), or $2.49 per occupant per year. Because the school has some mechanical ventilation and the recommended ventilation increase was lower than for the other schools, the penalty was lower.

Roof insulation could easily offset the increase in energy consumption from increased ventilation rates. In fact, net future facility cost energy savings of 7.4% (2.6-10%) are possible with this ECM and increased ventilation. This equates to $7.15 per occupant per year.

Case Study #2

School #2, in Steuben County, was originally constructed in 1894, with a 1954 addition resulting in a total area of roughly 62,600 square feet. During the academic year, approximately 550 students and 50 teachers and staff are in the school. Radon measures were proposed by the New York State Energy Office (NYSEO) through a prior study completed by Camroden Associates, Inc. in 1992. The Camroden report was aimed at determining a cost-effective approach to reducing indoor radon concentrations in the school. As presented by NYSEO, successful radon mitigation can be achieved through:

- A fan-powered ventilation system, or
- An active sub-slab depressurization system (ASD).

This study focused on the energy impacts of the proposed ventilation and ASD measures.

A base-case model for the existing school was developed and calibrated to historical energy bills. Annual energy costs determined by the model were $38,373, as follows:

- Natural gas consumption - 50,950 therms per year - annual cost $27,513 ($0.54 per gallon).
- Electric energy use - 197,457 kWh per year - annual cost $10,860 - aggregate electricity cost (including demand) $0.055 per kWh.
- Cost per occupant - $63.96 per year ($38,373/600).

Implementing the three ECMs recommended by SAIC (lighting, heating setbacks, and heating controls improvements) would reduce total annual energy consumption (gas and electricity) at the existing school by 28.5% ($10,926). The energy cost savings per occupant would be $18.21 per year. The estimated $35,308 implementation cost for the three ECMs would make the SPB 3.2 years, thus justifying the measures in terms of energy economics.

Increasing the outdoor air ventilation rates would increase the total annual energy cost (gas and electricity) by 16% ($6,152), or $10.25 per occupant per year.

The ECMs recommended by SAIC, if implemented properly, could easily offset the rise in energy consumption caused by increased ventilation rates. In fact, net interactive future facility cost energy savings of 12.4% (28.5% minus 16%) are possible with the ECMs and increased ventilation. This equates to $7.96 per occupant per year.

Case Study #3

School #3, an elementary school in Broome County, was originally constructed in 1964 and occupies a total area of roughly 52,000 square feet. During the academic year, approximately 600 students and 50 teachers and staff are in the school.

In 1996, the school broke ground on a 32,000-square-foot addition that will result in a total school area of approximately 84,000 square feet. The addition and the existing school combined will accommodate a total of 755 occupants, or 105 more than the existing school. School functions may be reallocated between the two sections to reduce occupant density in the existing school.

Data obtained during the site survey indicated the school is operated in an efficient manner. For example, nighttime setbacks are used, the oil-fired hydronic boilers are in good condition, a heating hot water reset schedule based on outdoor temperature is implemented, heating hot water circulation pipes were insulated, energy-efficient T-8 lighting with electronic ballasts was installed, and wintertime overheating problems were not reported. This level of efficiency at the school resulted in relatively low annual energy consumption. The school consumed less than a dollar per square foot per year for both electricity and oil combined, based on a utility bill analysis.

The existing school building (52,000 square feet, 650 occupants)

A base-case model for the existing school was developed and calibrated to historical energy bills. Annual energy costs determined by the model were $46,445, as follows:

- #2 heating oil consumption - 24,631 gallons per year - annual cost $15,518 ($0.63 per gallon).
- Electric energy use - 200,826 kWh per year - annual cost $30,927 - aggregate electricity cost (including demand) - $0.154 per kWh.
- Cost per occupant - $71.45 per year.

Implementing the four ECMs planned by the school (windows, doors, roof, and occupancy sensors) would reduce total annual energy consumption (oil and electricity) by 24.2% ($11,237). The energy cost savings per occupant would be $17.29 per year. The $292,400 estimated implementation cost for the four ECMs would make the SPB 26 years. Energy economics alone do not justify all these measures, as illustrated by the paybacks. The window and door replacements had paybacks longer than 30 years, whereas roof insulation had a payback of 8.8 years and occupancy sensors had an attractive payback of 3.5 years.

Increasing the outdoor air ventilation rates at the existing school would increase total annual energy cost (#2 oil and electricity) by 15.1% ($7,024), or $10.81 per occupant per year.

The ECMs planned by the school, if implemented properly, could easily offset the rise in energy consumption caused by increased ventilation rates. In fact, net future facility cost energy savings of 9.1% (15.1-24.2%) are possible with the ECMs and increased ventilation. This equates to $6.48 per occupant per year.

Capital improvement project

The 32,000-square-foot expansion project will increase total facility energy costs by 52.4% compared to the base case. This increase could have been less had the hot water circulation pumps been sized differently.

The modeling results predict a future energy budget of $70,781 per year, as follows:

- #2 heating oil consumption - 26,358 gallons per year - annual cost $16,606 ($0.630 per gallon).
- Electric energy use - 351,790 kWh per year - annual cost $54,176 - aggregate electricity cost (including demand) $0.154 per kWh.
- With estimated future occupancy of 755 for both buildings, the future energy cost per occupant will be $93.75 per year, or a 31% increase. However, the amount of space for each occupant will increase by 40%.

Case Study #4

School #4, in Orange County, was originally constructed in 1929, with a 1969 addition resulting in a total area of roughly 39,000 square feet. The school serves as both a middle and high school. During the academic year, 294 students and 40 teachers and staff are in the school, for a total occupancy of 334.

The school began construction on a 48,000-square-foot addition in 1995, which will result in a total school area of approximately 87,000 square feet. Unlike other more typical capital improvement projects, this expansion more than doubled the area of the existing school. The addition and the existing school combined will accommodate a total of 740 occupants, or 406 more than the existing school.

The existing school building (39,000 square feet)

A base-case model for the existing school was developed and calibrated to historical energy bills. Annual energy costs determined by the model were $30,663, as follows:

- #2 heating oil consumption - 20,848 gallons per year - annual cost $13,134 ($0.630 per gallon).
- Electric energy use - 133,811 kWh per year - annual cost $17,529 - aggregate electricity cost (including demand) $0.131 per kWh.
- Cost per occupant - $91.81 per year.

Implementing the four ECMs planned by the school (roof insulation, lighting retrofit, occupancy sensors, and space heating setbacks) would reduce total annual energy consumption (oil and electricity) by 36.8% ($11,280). The energy cost savings per occupant would be $33.77 per year. The $74,000 estimated implementation cost for the four ECMs would make the SPB 6.6 years. Energy economics justify these measures, as illustrated by the attractive payback.

Increasing the outdoor air ventilation rate at the existing school would increase the total annual energy cost (#2 oil and electricity) by 22.5% ($6,913), or $20.70 per occupant per year. Because there is no mechanical ventilation in the school, this is the total annual cost per occupant for ventilation.

The ECMs planned by the school and recommended by SAIC, if implemented properly, could easily offset the rise in energy consumption caused by increased ventilation rates. In fact, net future facility cost energy savings of 14.2% (22.5-36.8%) are possible with the ECMs and increased ventilation. This equates to $13.08 per occupant per year.

Capital improvement project

The 48,000-square-foot expansion will increase facility energy costs by 60.7% compared to the base case. The modeling results predict a future energy budget of $49,286 per year, as follows:

- #2 heating oil consumption - 21,396 gallons per year - annual cost $13,479 ($0.630 per gallon).

- Electric energy use - 273,336 kWh per year - annual cost $35,807 - aggregate electricity cost (including demand) $0.131 per kWh.

- With estimated future occupancy of 740 for both buildings, the future energy cost per occupant will be $66.60 per year compared to the base case of $91.81 per year, or a 27.5% decrease in future energy cost per occupant because the capital improvement project is being done in an energy-efficient manner.